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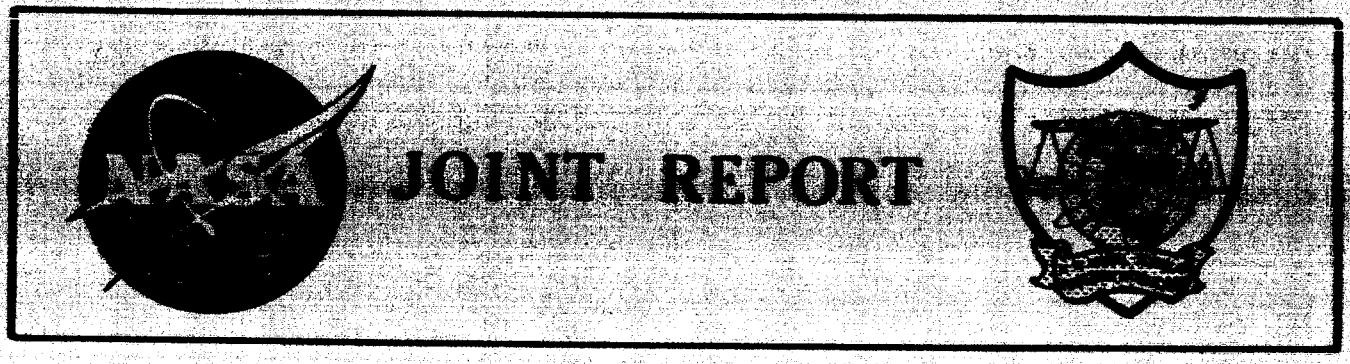

UNITED STATES NAVAL SCHOOL OF AVIATION MEDICINE
AND
THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

U. S. Naval School of Aviation Medicine
U. S. Naval Aviation Medical Center
Pensacola, Florida

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28 AUGUST 1962

Research Report

HUMAN PERFORMANCE DURING TWO WEEKS IN A ROOM ROTATING AT THREE RPM*

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28 Aug 1962 rejd Joint - - -

Bureau of Medicine and Surgery
Project MR005.13-6001
Subtask 1 Report No. 74

(NASA Order R-47)

(NASA CR --- ; BuMed-74) OTS!

Released By

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Commanding Officer

* This research was conducted under the sponsorship of the Office of Life Science Programs, National Aeronautics and Space Administration (Grant R-47).

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SUMMARY PAGE

THE PROBLEM

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To determine the fitness of healthy men to accomplish a variety of tasks during and after prolonged exposure to a slowly rotating environment.

FINDINGS

Four men were tested before, during, and after being rotated at 3 RPM for two weeks in the Pensacola Slow Rotation Room. The men also lived in the room preceding the commencement of the rotation. Tests of intellectual and physiological function were included. The principal finding was that no serious psychological or physiological deficit was detected during two weeks of rotation or during the subsequent readaptation to normal environment. The only test showing pronounced deterioration of performance at the beginning of rotation and upon returning to normal environment was the Graybiel-Fregly Posture Test. This means that any task requiring ordinarily difficult locomotion would be disturbed at these critical intervals. Ordinary walking with adequate visual reference was not so obviously affected. Results are discussed in relation to: problems of rotating space stations, the vestibular system, and experiments involving optically distorted visual information.

AUTHOR

ACKNOWLEDGMENTS

The authors express their appreciation to the entire crew of the Acceleration Unit, who operated the drive system throughout the two-week run, and especially to T. Gubala, ET2, who also assisted in the construction and installation of experimental apparatus.

For assistance in test administration and analysis, the authors are indebted to: L. Hardacre for the Conceptual Reasoning Test; A. Fregly for the Graybiel-Fregly Posture Test; J. Green for the Audio-Vigilance Test.

Special credit is due to J. Colehour for biochemical analysis; to R. Shoenberger for general helpfulness throughout the four-day prerotational and fourteen-day rotational run; to R. Upchurch, HM1, for his excellent logistic support; and to J. Cloud for exceptional accomplishment in preparation of the SRR for the experiment and in a quick repair of the drive system during the run.

INTRODUCTION

The principal objective of this experiment was to measure the fitness of healthy subjects to accomplish a variety of tasks during and after prolonged exposure to a slowly rotating environment. Previous experiments (3,7,9,11,17) had demonstrated that exposure to constant rotation at 1.0 RPM produced insignificant effects even in persons highly susceptible to motion sickness, that mild symptoms were experienced by some persons at 1.7 or 2.0 RPM, and that fairly severe symptoms were manifest in most persons at 5.4 RPM prior to exposure sufficient for adaptation. In the present experiment 3.0 RPM was chosen because it represented a good compromise between the conflicting desires to generate an adequate inertial force which might substitute for gravity in an orbiting spacecraft and the avoidance of unwanted side effects (3,9,20-23). For a space platform rotating at 3.0 RPM, a radius of 60 feet would be required to simulate the gravitational attraction of the moon and nearly 82 feet to generate one-quarter the earth's gravity. The duration of the run was set at two weeks to test for any undesirable secondary effects which might occur after the initial period of adaptation and also because of the likelihood that future space flights might be of similar duration.

APPARATUS AND PROCEDURE

The device used in this experiment was the Pensacola Slow Rotation Room (SRR) which is a nearly circular room (described in detail by Graybiel, Clark, and Zarriello, 7,) 15 feet in diameter and completely enclosed (Figure 1). It is capable of smooth acceleration and virtually vibration-free constant angular velocity (10). Communication between the SRR and the control room was accomplished by a two-way interphone which also provided auditory monitoring by control room personnel of conversations within the SRR. An ice box, sleeping bags, a toilet, electric cooking utensils, a sink, a television set, and a tape recorder afforded living conveniences for four persons for the duration of the experiment.

The three volunteer subjects for this experiment, aged 18, 18, and 19 years, were enlisted men in good health. None had any history of disease referable to the sensory organs of the inner ear. They exhibited usual sensitivity of the semicircular canals as indicated by caloric irrigation. Effort was made to ensure favorable motivation of the subjects by 1) explaining the importance of their participation, 2) providing a television set and recorded music on board for evening hours, 3) informing them of extra time "off duty" at conclusion of run, 4) arranging for publicity in local papers, and 5) permitting them their own selection of foods.

The experiment consisted of: 1) Four days of testing followed by three days of rest prior to the beginning of rotation; the subjects and the "on-board experimenter" lived on the SRR throughout the four-day testing period. 2) Fourteen days of testing aboard the SRR while it rotated at 3.0 RPM; all subjects and the on-board experimenter remained within the room throughout this period. 3) Three days of postrotation testing; subjects were tested on board for the first eight hours after rotation stopped and

Table I

Procedure for a Routine Day

1.	Urine Stop	0730
2.	Weight and Body Temperature	0745
3.	Coffee and Roll	0800
4.	Conceptual Reasoning Test	0800
5.	Sequence Test	0830
6.	Harvard Step Test	0900
7.	EKG, Respiration, and Dials	1000
8.	Midmorning Meal	1130
9.	Graybiel-Fregly Posture Test	1215
10.	Walking Test	1245
11.	Past Pointing	1300
12.	Accommodation and Convergence	1330
13.	Weight-Lifting	1400
14.	Achilles Reflex	1430
15.	Math Test	1500
16.	Audio Vigilance	1515
17.	Secured Testing and Free Time	1600 until retiring

4) The Graybiel-Fregly Posture Test (8) uses rails that are modifications of those originally used by Heath (14) in screening military personnel. In the present experiment only the two narrowest rails were used (1 1/4" and 3/4"). There were three trials on each of three tasks on the two rails: 1) walking heel-to-toe for five steps or until balance cannot be maintained with arms folded in front, 2) standing heel-to-toe for sixty seconds with eyes open or until the subject falls, 3) standing heel-to-toe for sixty seconds with eyes closed or until the subject falls. Score was the best two of three trials with a maximum score for walking of 10 (steps) and standing --120 (seconds). Subjects were given some practice on the rails prior to the static run.

Results of the Rail Tests are presented in Figures 5 and 5a and clearly reflect changes in performance with the onset of rotation and with readaptation to a static environment after rotation. By the fourth day the performance of all three subjects on the 1 1/4" rail was equivalent to their performance prior to rotation. This in turn was superior to their performance in a static condition before the benefit of practice. Two of the three subjects required approximately eight days to reach their previous performance level on the 3/4" rail. Results of standing with eyes open on the 1 1/4" rail approximate those of the Walking Test. Standing with eyes open on the 3/4" rail and with eyes closed on either of the rails showed variable results which were insufficient to show any adaptation effect during rotation or readaptation after rotation. After rotation, all performance on the rails declined and did not attain the maximum performance level until the afternoon of the third day of normal environment.

5) The Walking Test (17) requires the subject to fold his arms and walk heel-to-toe toward the center column from the periphery of the room and to return to the periphery. This test was then repeated with eyes closed. Each subject was scored on a five-point rating scale in unit deviations from his own norm prior to rotation. The deviation range is from 0 to 5 (no change,to inability to complete this task).

The Walking Test demonstrated a clear decrement in performance on the first day of rotation, with a gradual improvement through the first six days, after which performance attained the prerotation level (Figure 6). This test was not given after the rotation ceased because of its similarity to the rail test and to economize on subject testing time.

6) The Past Pointing Test was introduced by Bárány (in Dorcus and Mowrer, 4,) in 1911 and has long been used as a clinical index to the functional integrity of the vestibular apparatus and certain associated neural pathways. The subject was required to: a) blacken his finger with a grease pencil, b) fixate and point at a spot at eye level on a piece of graph paper, c) close his eyes, d) drop his arm, e) attempt to return to the target under four experimental conditions. The subject was given the following instructions: a) return to the target with straightened arm, b) return to the target in an arc to the right, c) tilt your head 45° to the left shoulder and return with straightened arm, d) tilt your head and bring your arm up in an arc, all with the

9) The Math Test, a simple test of arithmetic computation, is composed of 560 simple items alternating addition, subtraction, multiplication, and division (17). The subject was to work as quickly and as accurately as possible for ten minutes. In order to minimize practice effects, eight different forms of the test were administered. Scores were total number attempted and percent correct.

On the first day of rotation all three subjects showed a decrease in the number of correct responses on the Math Test, and all three showed a slight decrement in the number of problems attempted and in percent correct (Figures 8a, 8b, and 8c). This slight decline in performance may reflect a minor decrement in ability in this type of mental function as a result of the initial exposure to rotation. It will be necessary to observe more subjects to confirm whether or not this shift is attributable to chance, but irrespective of the outcome of further studies, it is clear that, by the second day, performance returned to the level of the prerotation tests and continued to improve for the two-week period.

10) Electrocardiograms and blood pressure readings were taken immediately after the Dial Test which was used as a stressor. Five dials were placed so that the subject was required to rotate his head and body through different complex arcs in order to view the dial and adjust the dial indicator. At the conclusion of 20 sequences of five dials (100 settings) electrocardiograms and blood pressure readings were obtained with the subject inclined 75° from the horizontal plane on a tilt board. In previous experiments (3,7,9,11,17) the Dial Test was proven to be a stressor particularly when performed at higher angular velocities of the SRR. No indications of any changes in EKG or blood pressure were found before, during, or after the two-week rotation run.

11) The Achilles reflex was elicited with the subject kneeling on a platform and was recorded by means of a photoelectric cell aimed at a uniform white field (adhesive tape) on the subject's heel. The photocell signal was recorded by a Sanborn recorder. Records were examined for response delay as well as duration and intensity.

There was no change in latency between the stimulus artifact and the peak contraction. An apparent decline in the magnitude of the peak contraction was noticeable in the second week of rotation, but this is possibly attributable to change in recording technique and the force with which the reflex was elicited (29,30). This issue can only be clarified with further experimentation.*

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*That strength and reflex activity of the limbs might be affected by continual bizarre vestibular influx to the brainstem was suggested by the work of Gernandt (6).

Test. Also there was no indication of any important changes in EKG, blood pressure, or respiration before and after stress tests during rotation.

The Math Test gave some evidence of a deficit during the first day of rotation. Although the decrement in performance was slight and the recovery took place by the second day of rotation, there are several reasons for careful consideration of this apparent temporary deficit. First, there have been a number of instances in which on-board experimenters have reported periods of apparent confusion. This has been particularly evident at higher angular velocities of the SRR. Second, if this effect is due to rotation, it occurs at a particularly critical time, namely, within the first day of exposure, a period which would presumably be of importance in establishment of an orbiting rotating space vehicle. Further systematic observation should be carried out.

The Rail Test and Walking Test showed great changes with the onset of rotation. There was a considerable deficit in these abilities with the onset of rotation followed by improvement in performance which eventually even surpassed performance before rotation commenced. Initial decrements in this kind of performance were to be anticipated from previous experiments and from an analysis of the conflicting sensory information which is presented in this unusual environment. For example, movement in a straight line within the room is actually movement in a curved path over the earth. Hence, the visual information conflicts with the proprioceptive information from the muscles and joints as a person attempts to move within the room. In addition to this, there is a gradient of centripetal acceleration which is detectable even though the greatest centripetal acceleration (at the maximum radius of the room) is of very small magnitude. These are seriously compounded by misleading information from the semicircular canal system whenever the head is tilted relative to the plane of rotation. The conflicting situation present here is analogous to that encountered in the inverted lens experiments (5, 15, 18, 19). In the latter experiments visual information is distorted and made to conflict with normal proprioceptive and vestibular information. In the present experiments visual information about spatial relations within the room is essentially accurate, but locomotion within the room is accompanied by conflicting proprioceptive and vestibular information. As adaptation ensues, the intention involved in the movements permits learning of anticipated sensory conflicts from the proprioceptive and vestibular systems which apparently gradually results in a CNS reorganization. Within a few days, walking and all movements are made without difficulty and without apparent sensory-motor disturbance. Upon cessation of rotation this new state of adaptation is now a source of difficulty. With movements of the head and body in the normal earth environment, the expected proprioceptive and vestibular information (16) which was learned on the room is no longer elicited. [As has been shown in previous experiments (11, 12) these movements now elicit reflex activity and sensory events directionally opposite to reactions which occurred soon after the beginning of rotation.] With time these compensatory reactions appropriate to a rotating environment dissipate, and this period is analogous to the recovery period required after the removal of distorting

Although the four men on board the room, three subjects and one experimenter, remained together night and day for more than two weeks, no problems from confinement were encountered. Possibly this is attributable to the constant availability of communications through a public address system and the outside experimenter entering once a day. Probably more important were instructions to subjects concerning the importance of their participation, and to ". . . assume the attitude of an astronaut and make the run without looking for personal difficulties." In addition, the subjects had television on board, were permitted to view favorite programs at night, and were aware of receiving news coverage in various media, which added a spirit of adventure to the experiment.

Many conveniences were made available to these subjects which would not be available to the space traveler. For example, subjects were allowed to eat food of their own choosing, including steak, pies, and cakes, as long as the foods were considered healthful. There was adequate room for exercise which permitted the subjects to actually improve on all of their strength tests. These factors were purposely varied from the restricted conditions which the astronauts will face in their first lengthy adventures into space in order to test the effects of rotation without side effects from restricted movement, unusual diet, et cetera.

One of the main problems which remains to be solved in regard to rotating space stations is the problem of transfer of habituation from one acceleration environment to another. It is clear, even at 3.0 RPM, that the habituation which takes place in this environment can produce minor disturbance upon returning to a normal earth environment. The magnitude of effects that will be produced by putting a person in a less stable environment after adapting to 3.0 RPM remains to be established by further experimentation. It will be a matter of practical importance to determine whether or not there is some program of acceleration exposure which will habituate a person to a rotary environment and also permit him to return from the rotary environment without the disturbing transfer effects which normally follow this exposure.

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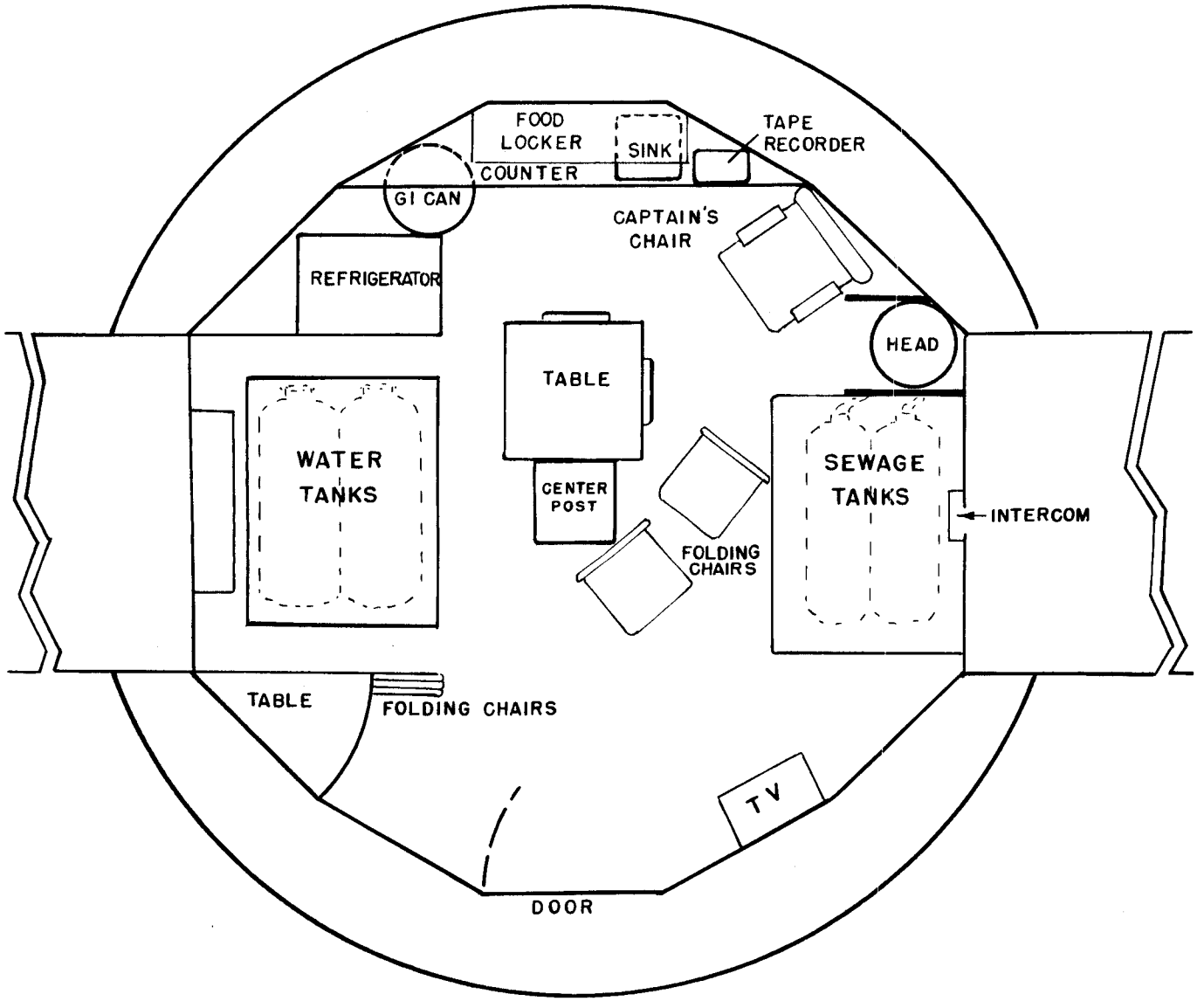

Figure 1

Slow Rotation Room

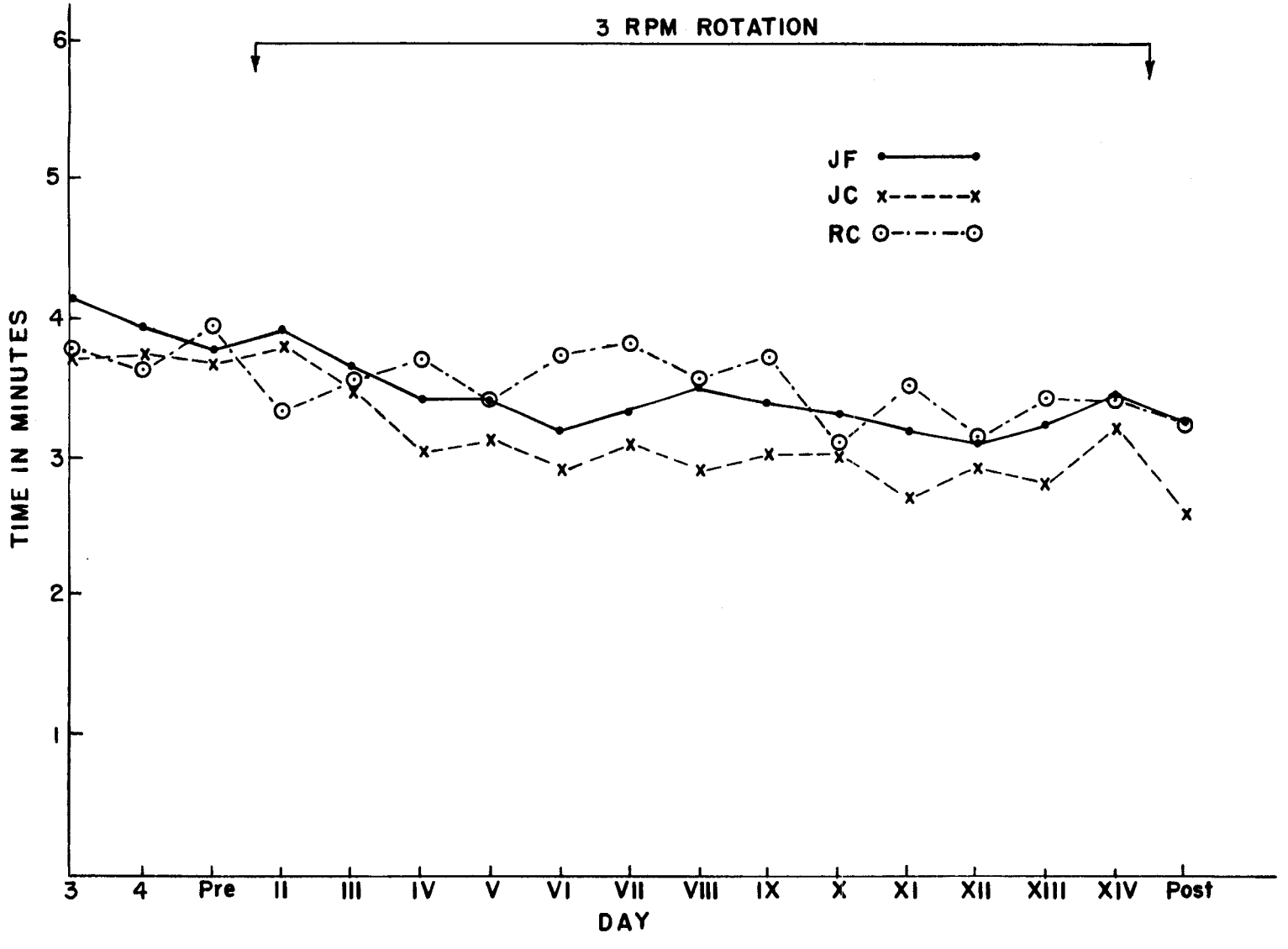

Figure 3

Sequence Test - Total Time for 5 Trials

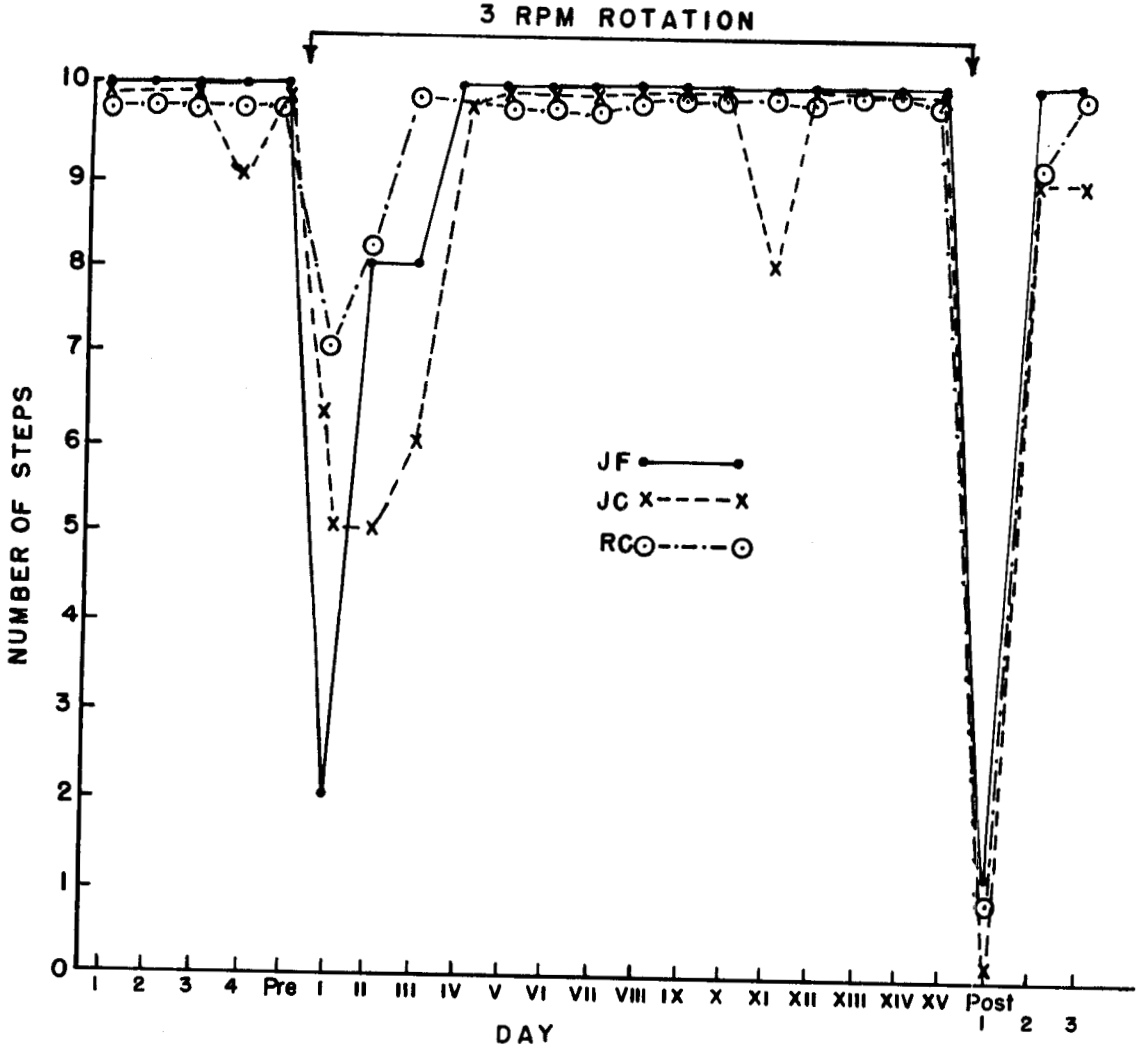

Figure 5

Graybiel-Fregly Posture Test - Total Number of Steps Walking Heel-to-Toe on 1 1/4" Rail with Eyes Open

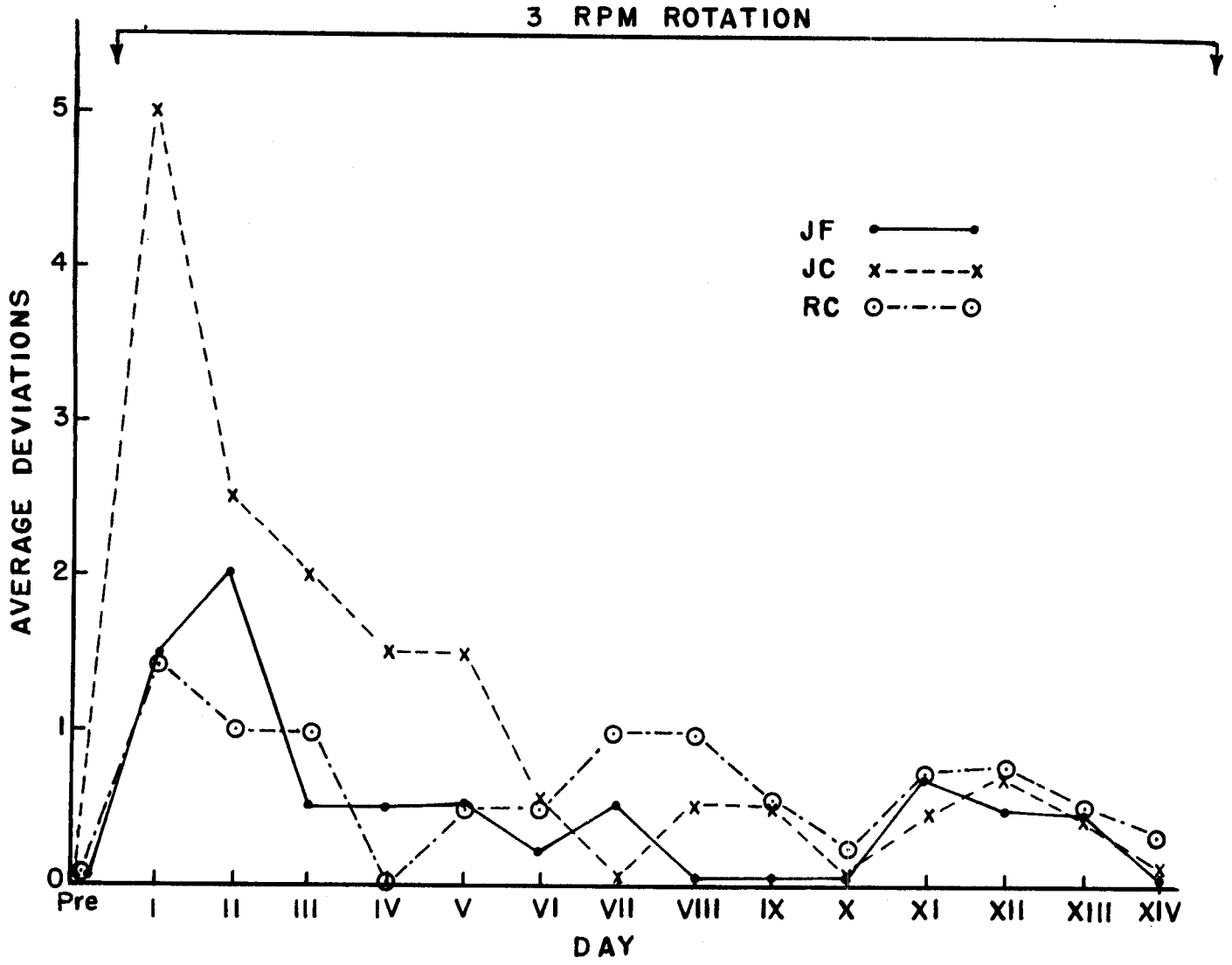

Figure 6

Walking Test - Average Deviation from the Norm (0) Walking Heel-to-Toe with Eyes Closed

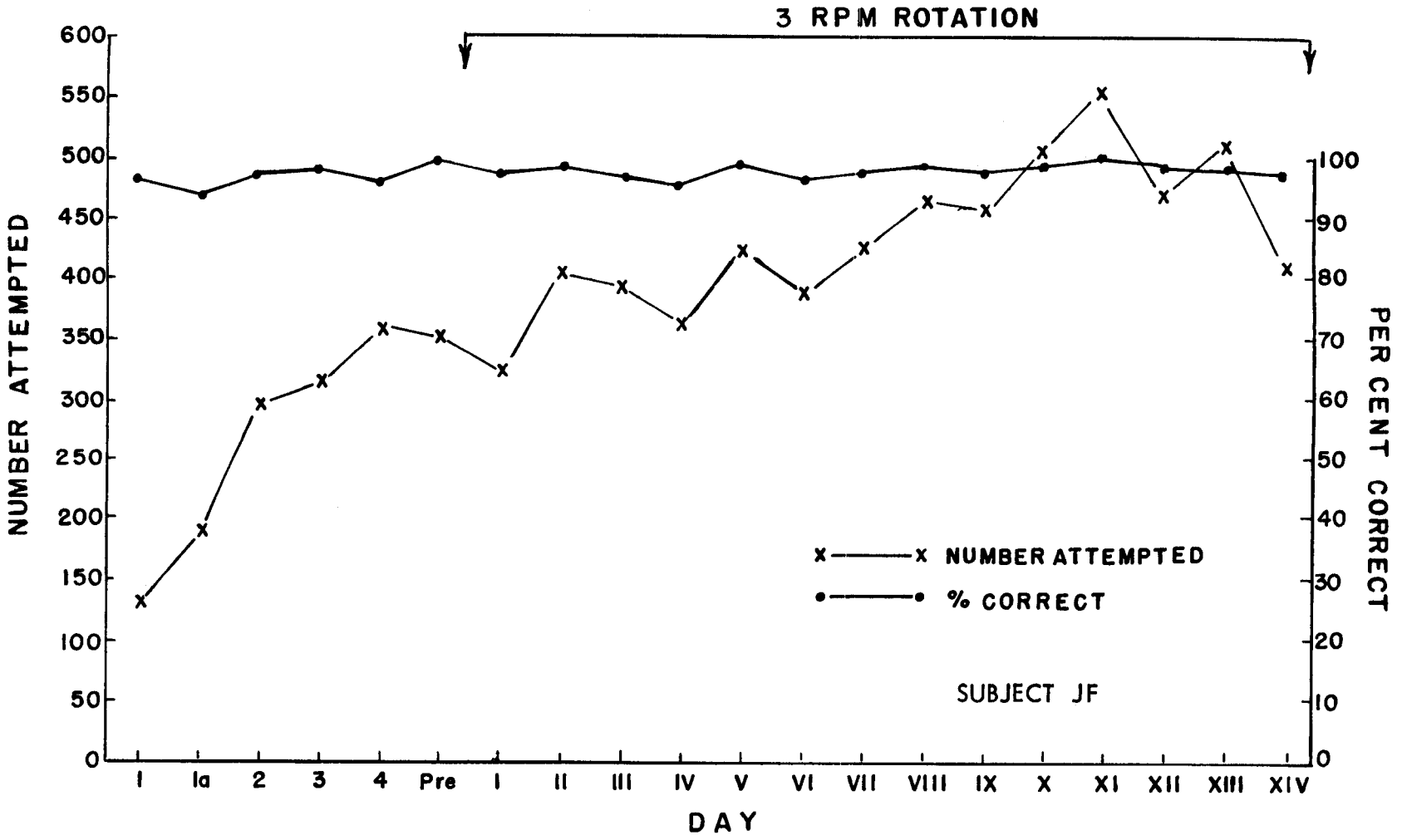

Figure 8a

Math Test - Total Number Attempted and Percent Correct

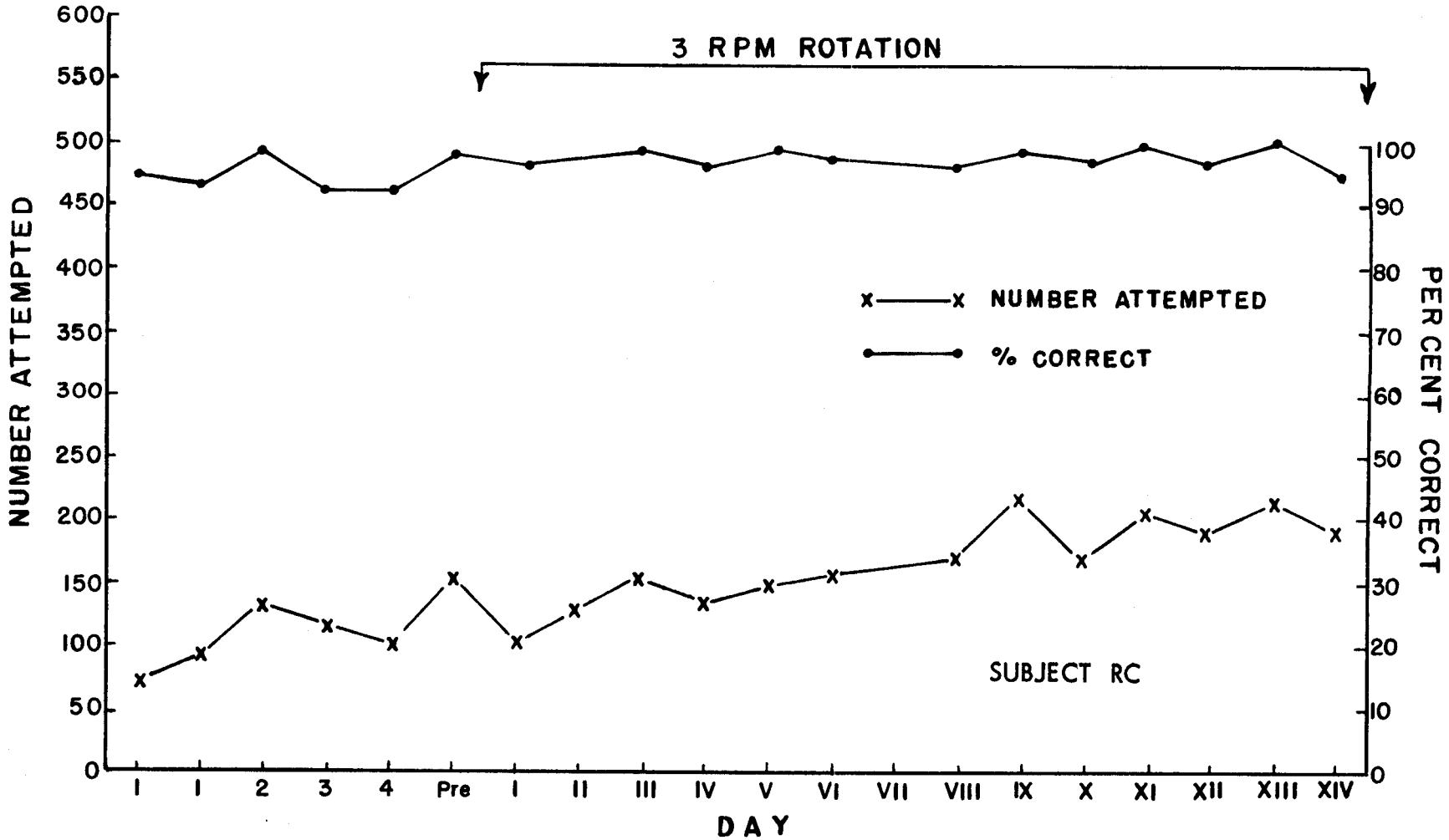

Figure 8c

Math Test - Total Number Attempted and Percent Correct